Historic, Archive Document
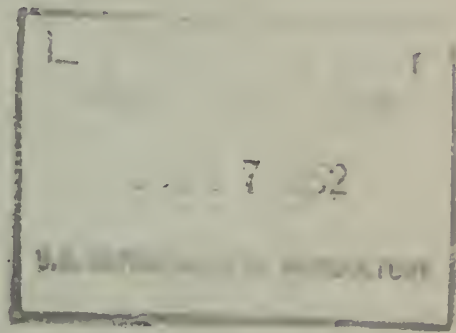
Do not assume content reflects current scientific knowledge, policies, or practices.

no. 114

DEVELOPING AND TESTING IRRIGATION WELLS

By

TOM O. MEEKS, Geologist

REGIONAL BULLETIN 114

GEOLOGICAL SERIES 4

MARCH 1952

Bulletin No.	Title and Author	Date
109	The Occurrence of Ground-Water in the Tijeras Soil Conservation District, Bernalillo County, New Mexico. Tom O. Meeks	April 1949
111	The Occurrence of Ground Water in the Alamogordo-Tularosa Area of the Otero Soil Conservation District, New Mexico. Tom O. Meeks	March 1950
112	Reconnaissance of Ground-Water Conditions in the Uncompahgre Valley, Colorado; Shavano and Uncompahgre Soil Conservation Districts. Tom O. Meeks.	Sept. 1950
114	Developing and Testing Irrigation Wells. Tom O. Meeks.	March 1952

Bulletins of the Geological Series may be obtained by writing to the Regional Office of Education and Information or the Regional Water Conservation Division, Soil Conservation Service, Box 1348, Albuquerque, New Mexico.

CONTENTS

CONTENTS   (Continued)

DEVELOPING AND TESTING IRRIGATION WELLS

By

Tom O. Meeks

INTRODUCTION

Purpose and Scope of the Report

The Soil Conservation Service in the Southwest Region cooperates with Soil Conservation Districts to furnish technical assistance to farmers and ranchers in determining the availability of ground water, selecting sites for stock and irrigation wells, and developing as satisfactory wells as physical conditions permit. In recent years there has been an ever increasing demand for assistance in developing and testing irrigation wells. The limited personnel available makes it impossible to render such assistance except in a very few cases.

The importance of proper development and testing of irrigation wells cannot be over emphasized. It may be more appropriate to speak of "constructing" rather than "drilling" a well because drilling alone is only a part of the complete operation of constructing an irrigation well that will deliver the most water at least cost.

Few facilities installed by farmers are more important and more expensive than the construction and equipping of an irrigation well, yet few structures are installed with as little attention and thought as is given to the installation of wells. Once the hole has been drilled, many farmers are reluctant to spend an additional few hundred dollars to properly develop and test the well, although the additional investment might save many times that amount over a period of years and might prevent loss of the well. There are many instances where lack of proper development after the well was drilled has resulted in later expenditures which greatly exceeded the cost necessary to do the job properly in the first place. Many wells have not been adequately tested after completion and, as a result, pumps and engines are not adapted to the capacity and pumping lift of the well. This results in inefficiency and increased costs of pumping water.

- 1 -

This paper is written so that the methods of developing and testing wells in unconsolidated and loosely consolidated materials will be available to work group personnel of the Soil Conservation Service, well drillers, and individual farmers and ranchers. Much of the information contained herein is available in various publications but many of these sources of information are not readily available to field personnel.

Acknowledgments

HYDRAULICS OF WATER WELLS

Some knowledge of the hydraulic characteristics of water wells is necessary to an understanding of the development and testing of wells. The yield of wells depends largely upon the character of the aquifer and the thickness of water-bearing material penetrated. Wells are engineering structures and their one purpose is to furnish the maximum amount of water available for economical pumping within the limits of well depth, method of construction and materials used.

Wells draw from unconfined water (water under water-table conditions) or from confined water (artesian water.)

The water table in pervious granular material is the upper surface of the body of free water which completely fills all openings in the material. The water table is an irregularly sloping surface. Irregularities may be caused by differences in thickness and permeability of water-bearing formations or by unequal additions or withdrawals of ground water.

All ground water moves from a place of recharge to a place of discharge. The movement is, in general, in the direction of the greatest slope of the water table. Under water-table conditions, the water behaves much like that in a surface

reservoir, except that friction causes it to move much more slowly. When water is withdrawn, it comes from storage within the aquifer by draining water from the pores of the water bearing material. As the well is pumped, it continues to draw water from storage until the amount of water withdrawn is balanced by an increase in recharge or a decrease in natural discharge, or both.

When a well is pumped, the static water level in the vicinity of the well is lowered. This lowering, or drawdown, causes the water table to take the shape of an inverted cone with the well at the apex. At increasing distances away from the well the lowering becomes less and less until, at the limit of influence of the well, the slope of the cone merges with the water table. The shape of the cone of depression depends upon the permeability of the water-bearing formation. Shallow cones will form where the aquifers are highly permeable and composed of coarse sands or gravel. Steeper cones will develop in less permeable aquifers.

When pumping first starts, some water-bearing material will be unwatered by the drawdown of the water table and the water drained from this material will move to the pumped well. Thus, for a short time after pumping begins, most of the water pumped will come from water which was stored close to the well. As more and more water is withdrawn, the cone of depression must deepen and grow laterally until a hydraulic gradient toward the well is established. Water moves along this gradient from farther and farther away. As the water level at the well continues to drop, the cone of depression formed by this hydraulic gradient continues to expand, but at a steadily decreasing rate if the pumping is uniform.

Thus, as pumping continues, the drawdown extends to greater distances from the well. As water is withdrawn from storage, the effect of withdrawal will eventually extend to the intake area and result in a lowering of the water table there so that an increase in the rate of recharge may result. If the well is near an area of natural discharge, the cone of depression may reach this area and result in a reduction in the natural discharge.

Under artesian conditions water is confined under pressure between two layers of impermeable rock. At its intake area the water is under water-table conditions and, after being absorbed by the aquifer, it moves down the slope of the water

- 3 -

table until it reaches the overlying impermeable bed. Part of the water may pass above the impermeable bed and continue to move under water-table conditions and part of it moves beneath the bed. The water beneath the impermeable bed is confined as though it were in a pipe. If the aquifer is penetrated by a well, the water will rise to a height above the bottom of the confining bed equal to the pressure head in the aquifer at that point. If the head happens to be above the land surface, the well will flow. When water is withdrawn, it comes from storage until the effect extends to the intake and results in a lowering of the water table there and perhaps an increase in recharge. The water table in unconfined aquifers and the piezometric surface of an artesian aquifer (the level to which water will rise in artesian wells) behave in the same manner. Because there is usually a greater amount of available water in storage in unconfined aquifers, the cone of depression spreads much more slowly than in artesian aquifers.

Water-table aquifers may be recharged directly from above, but artesian aquifers are recharged only in areas where the upper confining bed is absent and water can enter from the surface or from overlying aquifers.

Interference of Wells

The drawdown and the radius of influence of a well are dependent upon the amount of water pumped and the character of the water-bearing material. When two wells are located too close together, their cones of depression overlap and neither will yield as much as it would if not interfered with.

The area of influence can be determined only by measuring the drawdown at various distances away from the well. The radius of the area of influence may vary from about 100 feet to two or three thousand feet. In areas where the radius of influence has not been determined, a spacing of three hundred feet or more would probably be a minimum, and spacing for wells yielding 600 to 1000 gallons per minute should probably be 1000 to 2000 feet.

Size of Wells

The common idea that doubling the diameter of a well doubles

the yield is erroneous. In any given aquifer a well yields in proportion to the depth it penetrates the water-bearing stratum. The yield of a well is a function of the flow of the water and the area made tributary to it by the depression of the water level in the well, rather than the size of the well. It is true that there is some increase in yield with an increase in diameter but it is usually a very small percentage. According to Tolman (11, pp. 391) a twelve inch well will yield 10 to 15 percent more water than a 6 inch well, and a 48 inch well will yield from 20 to 35 percent more than a 12 inch well, all other factors being equal. Table 1 shows the relationship of diameter to yield for wells of various sizes in unconsolidated alluvial material.

Table 1 - The relation of Diameter to the Yield of Wells:

WELL DIAMETERS

2"	4"	6"	8"	12"	18"	24"	36"	48"
INCREASE IN PERCENT								
0	10	15	20	25	33	38	48	55
	0	5	10	15	23	28	38	45
		0	5	10	18	23	33	40
			0	5	13	18	28	35
				0	8	13	23	30
					0	5	15	22
						0	10	17
							0	7
								0

(From Edward E. Johnson, Inc., Saint Paul, Minn., Bull. No. 1238, revised June 1947.)

Factors which should govern the size of a well are: the amount of water expected and the character of the water-bearing material.

Obviously, the size of the casing limits the size of pumps which can be installed and the well should be large enough to accommodate a pump of sufficient capacity to furnish the

available water. The inside diameter of the casing should be
at least four inches greater than the diameter of the pump
bowls.

An important factor in determining the size of a well is the
material of the water-bearing strata. Other conditions being
equal, if a well is installed in fine water-bearing sands, the
amount of sand entering the well is inversely proportional to
the size of the well. This is because of the fact that, when
pumping is at a uniform rate, the velocity of water flowing
into the well is inversely proportional to the diameter of the
well. Since sand of each grain size requires a definite
velocity to dislodge it from its bed and carry it in a stream
of water, larger diameter wells will sand up less than smaller
wells. The size of well is of lesser importance when the
aquifers are composed of mixtures of coarse sand and gravel.

TEST WELLS

In areas where the water-bearing formations are discontinuous,
it will be difficult to select a site where a satisfactory well
may be assured. Under such conditions, it will be advisable
to drill one or more test holes of smaller diameter, if the
expense is not too great, before selecting the exact site for
the irrigation well. In alluvium filled valleys, test holes
should be drilled at intervals along lines generally at right
angles to the course of the valley, to locate gravel filled
channels and thus determine the best location for the irriga-
tion well. If the cost of these wells is not excessive, the
test wells will be an excellent investment, if they are
instrumental in finding the most satisfactory site for a well.

Test wells may also serve other useful purposes. They will
determine the exact depth and thickness of the water-bearing
formations and the material of which they are composed. With
this information, the driller can select the proper size of
perforations to use and can perforate the casing before plac-
ing it in the hole. He can also determine whether the well
should be gravel packed and, if it should, he can make provi-
sion to do an efficient job of it with a minimum of cost.
Test wells may also be used to locate gravel-filled channels
and thus determine the best location for the irrigation well.

The question naturally arises as to whether the test well may

be enlarged and used for the irrigation well. There are some disadvantages in constructing an irrigation well at the exact site of the test hole. If the test hole is crooked or out of plumb, the drilling tools will usually follow the test hole, resulting in a poor irrigation well.

In many alluvial areas where the formations change rapidly, it is advisable to drill the main well close to the test hole so that the same conditions will be encountered.

KEEPING WELL RECORDS

The importance of keeping a careful and accurate record of a well as it is drilled and developed cannot be emphasized too strongly, and it should be considered just as much a part of the driller's contract as the drilling and development of the well.

The owner should insist that the driller keep a careful log, made up as drilling proceeds, recording the material passed through and describing it as best he can. This daily log should also include the progress made with the casing, any variations in water level, thickness of water-bearing strata, size, number and location of all perforations, and a record of the development and testing of the well.

Such records are of great value in any study of underground waters, and are essential to proper development of the well. These records may be of considerable value to the owner, particularly if trouble develops with the well and repairs, cleaning or redevelopment become necessary. Some states require that logs of all water wells be filed with the appropriate state agency.

The Water Conservation Division, Soil Conservation Service, maintains a file of well records and other ground-water information for each Soil Conservation District within the Region. Work Group personnel should encourage cooperators to require well logs to be kept at the time a well is being drilled, and furnish a copy for the regional files. These records are useful in selecting sites for other wells in the vicinity and are available to any interested persons or agencies. Well record forms may be obtained from the Regional Water Conservation Division.

CONSTRUCTION OF WELLS

Gravel Envelope Wells

Gravel treatment of wells is a subject which is much misunderstood, both as to its purpose and method of installation. Many wells have been gravel packed which did not need such treatment and others, which could have been improved by a gravel envelope, have not been treated.

The basic reasons for gravel treatment of wells are: 1) to obstruct the movement of fine sand into the well, 2) to increase the effective diameter of the well and thereby reduce the velocity of water entering the well, thereby reducing the amount of sand carried into the well, and 3) to fill cavities which develop near the well during pumping.

The question of whether a well should be gravel treated can be answered by determining whether the maximum amount of water can be. developed from the formation without gravel treatment. If it can, gravel treatment is unnecessary and only adds to the expense.

When water is pumped from a formation composed of fine sand, or a mixture of sand and gravel, sand is drawn out and a cavity may be produced. If the water-bearing strata are overlain by a harder stratum, the cavity may be confined to the aquifer. If no thick, hard beds exist, sand may continue to be pumped from the well until there is a serious cave-in at the surface. In extreme cases, such a cave-in will cause damage or loss of the pump and well.

Gravel Treatment Methods

Natural Gravel Treatment:

If the water-bearing strata contain a considerable amount of coarse gravel, the installation of a gravel envelope will usually not be necessary because, as the fine material is removed by pumping, the gravel which will be left will make just as effective a screen as could be produced by adding gravel. Where this situation exists, the perforations must be small

enough to retain sufficient gravel outside the casing to form the envelope.

A danger in this type of development is, if the formation contains an excessive amount of fine material, too much of this material may come into the well before the coarser particles can build up around the casing. Excessive movement of fine material into the well leads to caving, which is hazardous to the well.

When this condition exists, gravel must be fed into the well to replace the fine material being removed. This may be done by means of an outer casing or by means of gravel feed holes.

Gravel Filling of Cavities Produced by Pumping:

Quite often, when a well is drilled into fine material, a cavity is produced during pumping. Under continued pumping, this cavity may extend to the surface. The common practice when this occurs is to fill the cavity with gravel which settles around the casing as more sand is pumped out.

This method is unsatisfactory because the gravel cannot be placed accurately around the casing and usually this method will require more gravel than other types of gravel treatment.

Excessive caving of fine material can often be prevented by pumping at reduced rates until the gravel pack has settled around the casing and filled the void caused by removal of fine sand.

Gravel Packing through Gravel Feed Holes:

Gravel feed holes are sometimes used to place gravel around a well.

After the well has been drilled, smaller holes, usually six or eight inches in diameter, are put down around the central casing. They are drilled only to the top of the perforated section or screen so that gravel may be placed around the entire depth of perforations. The number of feed holes may vary, but a minimum of three is usually necessary to obtain a satisfactory job.

The holes should be spaced equidistant around the central well and should not be over four feet away from it. A closer spacing of about a foot will usually prove most effective.

Gravel is fed into the holes as the well is pumped or surged. As there will be a tendency for the gravel to bridge in the holes, it may be necessary to jar the pipes occasionally or run water into them to dislodge the gravel.
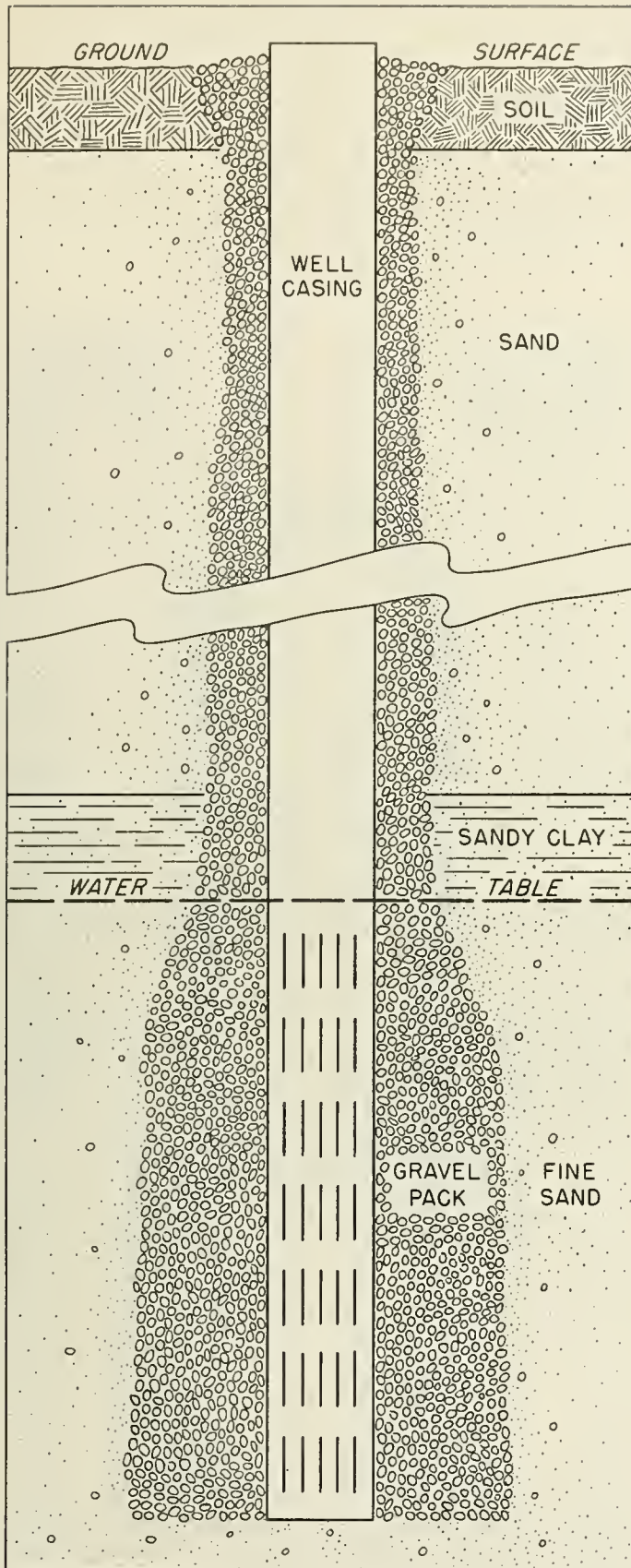
If the formations above the water strata are fine sand which flows freely, they may settle down faster than the gravel can be fed in through the pipes. For this reason, this method should not be used where this condition exists unless there is a hard stratum above the aquifer.

Because this method is expensive and not always reliable, it is not recommended except on wells where gravel packing was not anticipated before the well was drilled and other methods cannot be used.

Gravel Envelope Method:

One of the most effective methods of gravel treatment is to sink a casing to the bottom of the well large enough to accommodate the permanent well casing and the thickness of gravel decided upon. Thickness of gravel envelopes usually ranges from three to nine inches and a pack greater than twelve inches may cause the well to become clogged. After the hole has been drilled, the permanent casing is lowered into the hole and centered, with perforations opposite the water-bearing material. Gravel of uniform size is then placed between the two casings and the outer casing is withdrawn as the placing of the gravel proceeds. The gravel filling is carried upward until it is a few feet above the water-bearing strata.

In some cases, the outer casing is left in place. This is usually done if the water-bearing formations are very fine or if there is danger of caving. If the outer casing is left in place, it should be perforated opposite the water-bearing strata. Leaving the outer casing in place is an additional safeguard against caving but, when the gravel is confined between the two casings, the pore spaces may become clogged, with a resulting decrease in permeability.

In this method, grovel is fed oround the cosing ot the ground surfoce ond ollowed to settle oround the cosing os fine sond is pumped out. This method is widely used but is not os effective os other methods. This method is commonly used where the need for grovel pocking wos not onticipoted, ond covities developed during pumping.

Figure I. Gravel Filling of Cavity Produced by Pumping.
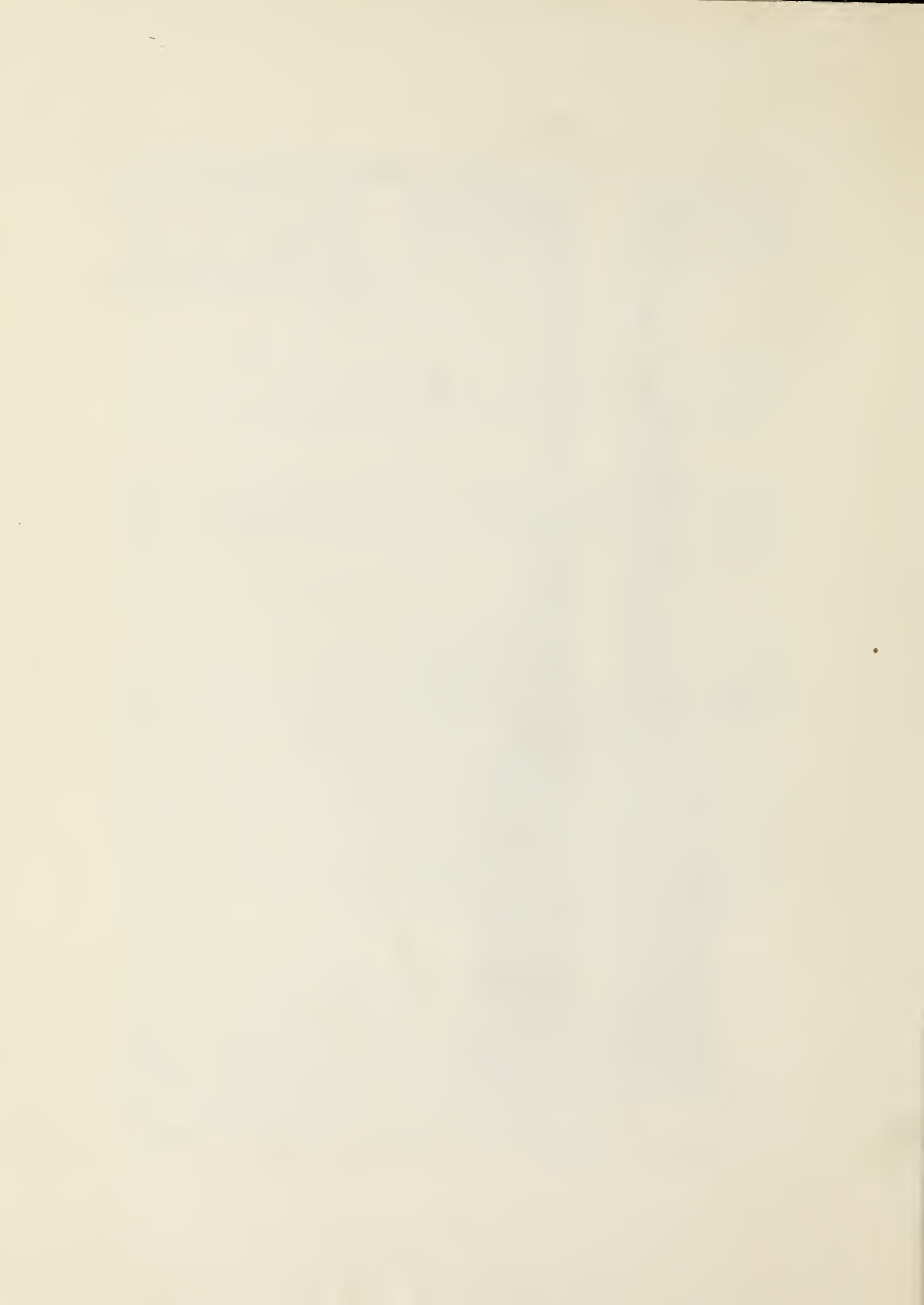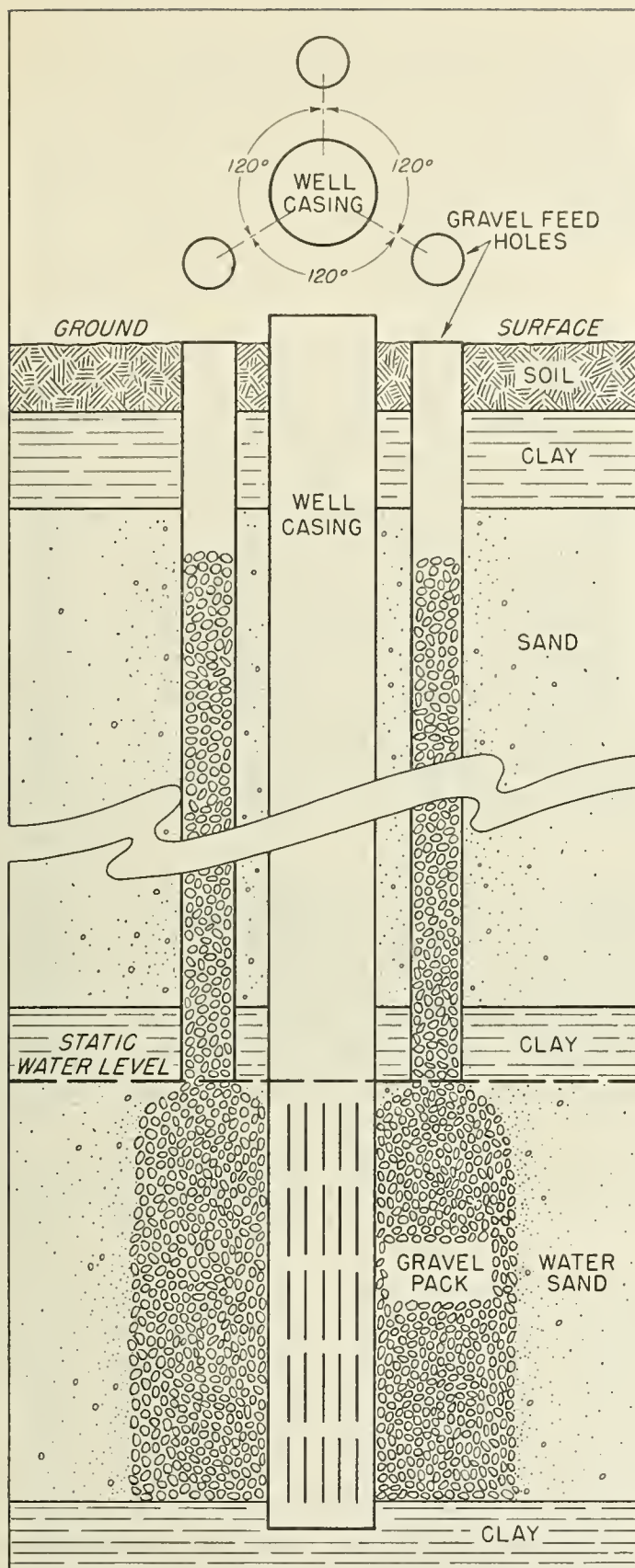
This method is sometimes used on wells already drilled where gravel packing is necessary, and other methods connot be used. It is expensive and not entirely relioble. The gravel feed holes ore drilled oround the well to o depth corresponding to the top of the perforations. Six or eight inch holes are usuolly used. A minimum of three holes is usually necessary. Distonce from the centrol well is usuolly one to four feet. Grovel is fed into the holes os the well is boiled or pumped.

Figure 2. Gravel Packing Through Gravel Feed Holes.

In some cases, gravel packing can be accomplished by the use of an enlarged shoe, which provides an annular space between the casing and the wall of the hole. This space is kept packed with gravel as the casing is sunk. It is essential to maintain a continuous column of gravel from the bottom of the well through the thickness of the aquifer and, if more than one aquifer is encountered, the gravel packing should be continuous through all aquifers.
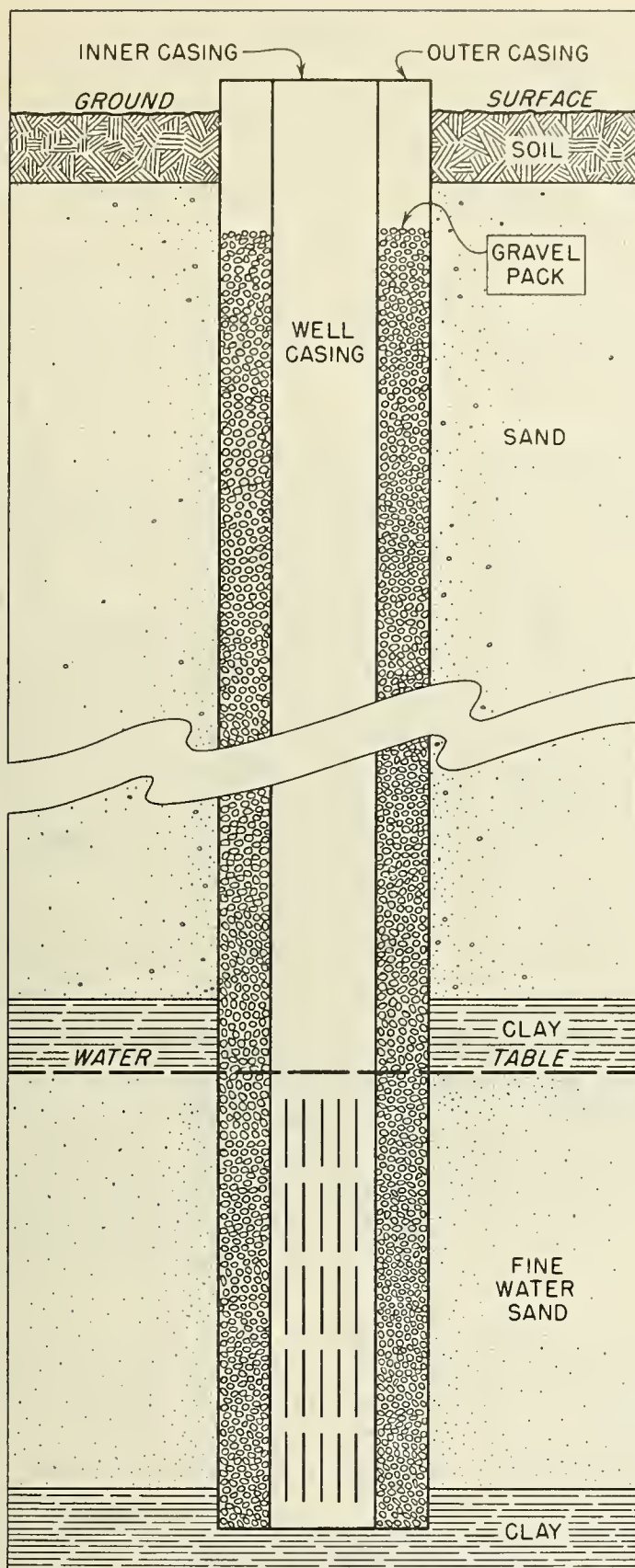
Some drillers prefer to place the gravel up to the static water level or to the ground surface. This is usually not necessary where only one aquifer is involved but where several water-bearing strata have been penetrated, the gravel envelope provides continuous passage for the water from one stratum to another. If the casing is not perforated opposite one or more of these strata, the water would flow through the gravel to the perforated portions of the casing. However, if there is any danger of contamination, the gravel envelope should not extend far enough above the perforations to allow contaminated water from higher strata to penetrate to the lower aquifers which are being developed. Gravel envelopes around artesian wells should be thoroughly sealed at the top of the artesian aquifer to prevent leakage into shallow, non-artesian formations.

If a gravel envelope is to be placed in a well drilled by the hydraulic rotary process, the outer casing is unnecessary because of the clay lining which is built up on the inside of the hole. The perforated casing is centered in the hole and the gravel added while the clay lining is being washed from the hole.

Gravel Treatment of Wells in Uniformly Fine Materials:

A uniformly fine formation has a larger percentage of voids than a formation containing coarser particles. However, due to increased surface tension in the finer deposits, their ability to transmit water is much less and water will move to the well more slowly, resulting in a lower yield than for wells in coarser materials. The use of a screen which will hold out the fine sand may not be feasible since it will also hold out water. In addition, the screen will be susceptible to clogging unless a gravel envelope is placed around it. When a uniformly fine aquifer is all that is available, arti-

INNER CASING — — OUTER CASING

GROUND   SURFACE

SOIL

GRAVEL
PACK

WELL
CASING

SAND

CLAY
TABLE

WATER

FINE
WATER
SAND

CLAY

Figure 3. Gravel Envelope Treatment

An outer casing is sunk the full depth of the well. The inner casing is centered in the well and gravel fed between the casings. As the gravel is fed into the well the outer casing is slowly pulled. After the gravel packing has been completed, development of the well is carried out. Where the need for gravel treatment has not been anticipated, this method may be used if the outer casing is large enough to place the inner casing. The inner casing need be only large enough to accommodate the pump. Space between the casings should be at least three inches.

ficial gravel treatment is the only method which will permit maximum development. In treating this type of well, the outer casing is sunk approximately to the top of the water-bearing strata. A screen of proper sized openings should be installed on the inner casing. The inner casing is bailed or drilled into place below the outer casing, with the gravel being fed into the space between the inner and outer casings as they are bailed into place. Surging is carried on at the same time to keep the settling gravel free from fine sand. Surging in this type of well should be carefully done and should be less intensive than that used in other wells.

After the gravel has sufficiently settled around the casing to prevent sand from moving into the well, the well should be developed in the regular manner. More gravel must be fed into the well as development proceeds.

Development is completed when no more fine sand is brought into the well. As the gravel will settle during the development and even during the final pumping, a considerable amount of gravel should be placed above the top of the perforations before the outer casing is removed. If the casing is not set on a hard or relatively impervious stratum, the bottom of the inner casing should be plugged.

Size and Placing of Gravel:

It must be remembered that one of the principal purposes of the gravel screen is to keep fine sand out of the well and to provide free passage for the water as it approaches the perforations. A mixture of gravel of various sizes is unsatisfactory because the smaller particles fill the spaces between the larger ones, reducing the voids and increasing the resistance to the movement of water.

There is a wide range of opinion as to what size gravel is the most effective and no definite grade size can be given to cover all situations. The most satisfactory size of gravel to use will usually be governed by the method of placing the gravel in the hole and the size of perforations in the casing.

Screened, pea-size gravel will be satisfactory under most conditions, if the perforations are small enough to prevent the gravel from entering the well. Many wells have perforations
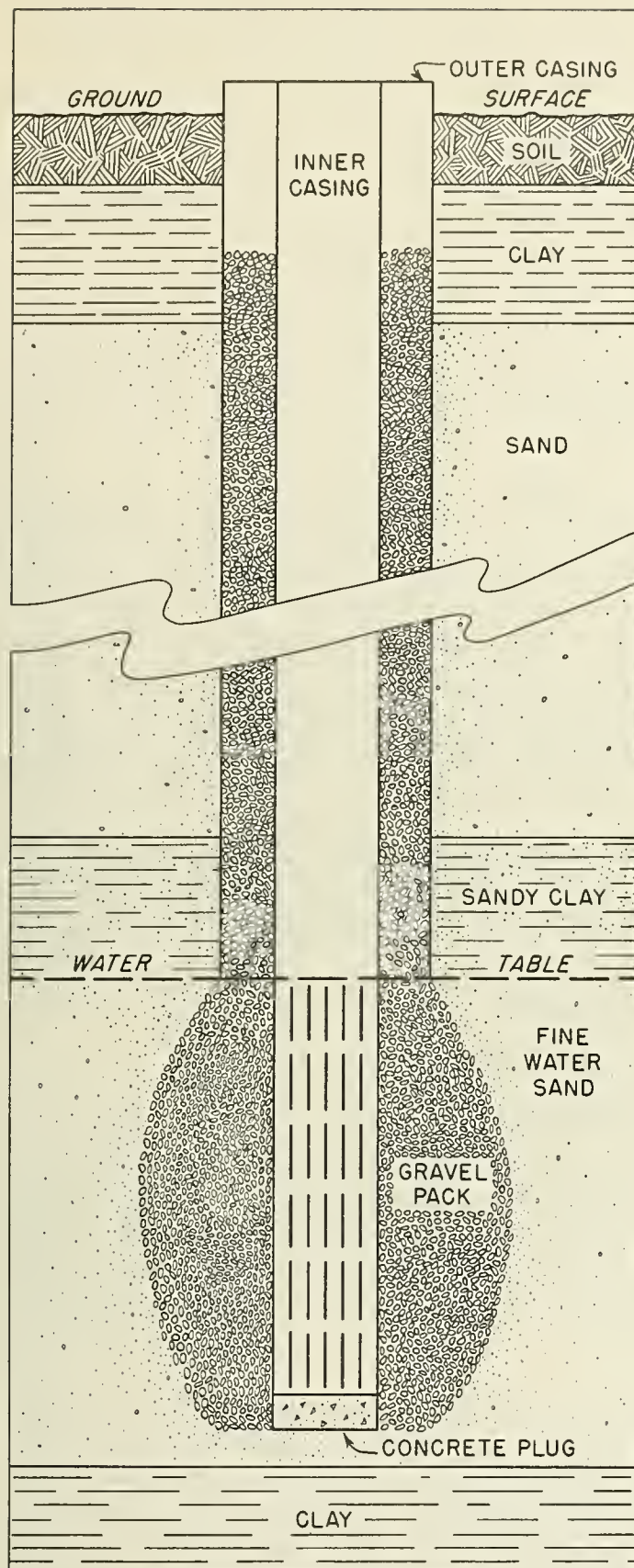
The outer casing extends to per-forated section and gravel is fed in as the inner casing is drilled or bailed into place. If the inner casing is not extended to the lower clay layer the bottom of the casing should be plugged. In wells where the water bearing formations are relatively shallow, the screen or inner casing may be equipped with a cone on the bottom, and bailed into place. During this process graded gravel is constantly placed around the inner casing. This method will usually require more gravel than the gravel envelope method, (Fig. 3).

Figure 4. Gravel Treatment of Wells in Uniformly Fine Materials.

ranging from 1/4 inch to 3/8 inch in diameter, with some open-
ings being even larger. Obviously, if such wells are to be
gravel packed, the gravel must exceed the size of the slots in
the casing or it will enter the well. The size of the annular
space around the casing will also be a determining factor in
selecting the size of gravel to use. If only a small space is
available, the larger sizes of gravel will bridge more easily
than smaller particles. If gravel is being fed into the space
around a casing, caused by a cavity developing in the water-
bearing formation, an intermediate or small size gravel will
reach the casing and fill it before large gravel. In general,
if various sizes of gravel are available, a size ranging from
1/2 inch to 3/4 inch will be the most effective.

Although gravel is usually shoveled into the space between the
outer wall or casing and the inner casing, the best method of
placing the gravel is by using a small diameter pipe or down-
spouting. The end of the pipe is placed near the bottom of
the well and the gravel is fed in slowly and evenly until it
has filled around the casing to a height of 4 or 5 feet. The
pipe is then raised about the same amount and the process re-
peated. To prevent clogging, the pipe should be about 4
inches in diameter.

If the gravel is fed around the casing too fast or it is too
large, bridging may occur. If this happens, it may be neces-
sary to tamp the gravel with a rod or to wash it loose with
water.

The Use of Well Screens

Screens have not been used in the southwest to the extent
which their merits justify. A well screen is a device on the
lower end of a well casing which allows the maximum amount of
water available to flow into the well casing without excessive
resistance at the screen and prevents passage of fine sand
during pumping.

Screens are made from a variety of materials and with a wide
variety in shape and size of slots. In the past, screens were
designed with small openings which would hold out as much sand
as possible. With increased knowledge of hydraulics of wells,
this practice has now been reversed and screens are selected
which will let in as much as 80 percent of the water-bearing
material into the well. It is essential that a well screen

have openings which will permit development of the well under any conditions.

The primary consideration in selecting a screen is to choose one which provides the maximum amount of open area consistent with strength and the grain size of the formation in which the screen is to be used. Most manufacturers of well screens will determine the correct type of screen from samples of the water-bearing formation submitted to them.

A disadvantage of well screens is the fact that they are subject to corrosion and incrustation which may cause failure of the well.

Perforating the Casing

Casing may be perforated before placing it in the well if the location of the water-bearing stratum is known. This is the most satisfactory method of perforating the casing. In the southwest region, casing is commonly perforated by use of a cutting torch before it is installed in a well. As there are few instances where the location of the water-bearing stratum is known, the casing is often perforated throughout its entire length before it is placed in the well. This practice is usually unnecessary and is often hazardous to the use and maintenance of the well. Only those portions of the casing opposite water-bearing formations should be perforated.

There are various methods of perforating the casing in place but the Mills knife is the one commonly used in water wells. The Mills knife consists of a frame which holds the perforating knife, a string of pipe for pulling the lever that forces the knife through the casing and a cable for holding the perforator in place. The device is started at the bottom of the casing and worked toward the top. Since the water-bearing formations may be accurately located while the well is being drilled, the perforations can be made at these levels, which makes this method of perforating generally satisfactory. If the pumping test shows that perforating has been incomplete, great care should be exercised in making additional perforations. If not careful, a second use of the cutter may result in over perforation and the casing will probably be ripped and torn. The resulting large holes may cause collapse of the well soon after its completion. Even if the well does not collapse,

large amounts of sand and gravel may enter the well and cause injury to the pumping equipment.

The number and size of perforations required is difficult to determine. There should be enough perforations to enable the water to enter the well without unnecessary loss of head and not enough perforations to seriously weaken the casing. If samples of the water-bearing material are taken, a satisfactory size of perforations may be selected. It is commonly considered that the size of perforations should be chosen so that about 60 percent of the grains will be retained outside the casing. Slots spaced from 3 to 6 inches apart around the circumference of the casing and from 5 inches to a foot lengthwise usually give satisfactory results under most conditions.

DEVELOPMENT OF WELLS

Well development is a mechanical process which requires knowledge and experience on the part of the well driller. Many drillers do not understand development work, with the result that many wells are never properly developed and the maximum results never obtained. Most people who hire well drillers do not understand the importance of properly developing the well and are reluctant to pay the additional cost necessary to obtain a properly constructed well. In order to get the best results possible, it is just as important to properly develop the well as it is to drill a straight hole. The yield of a well per foot of drawdown has been more than doubled in many cases by proper and thorough development. Complete development is accomplished when a well can be pumped at any rate within its maximum yield without pumping sand.

Bridging of sand in water-bearing formations is important and knowledge of the process of bridging is necessary to an understanding of development work. When water is pumped from a well, there is a tendency for sand particles in the formation to move toward the well. As the steady pull of pumping is in one direction, the finer sand grains will wedge against each other and bridge across openings between the coarser grains. The only way in which bridging can be prevented is by keeping the water agitated by reversing the direction and rate of flow. This is the primary purpose of development.

Development by Surging

Surging is one of the most effective and commonly used methods for developing wells in sand and gravel formations. Surging is carried out by working some type of block or plunger up and down in the well so that the water is alternately forced out of the well into the surrounding formation and then allowed to flow back into the well. This action loosens the fine sand or gravel particles around the perforations in the casing and carries the finer particles into the well where they can be removed.

In operating a surge block, the block is secured to the drilling line and lowered into the well until it is about fifteen feet into the water. When the tool is in place, the machine is set for long stroke and the surge block is worked up and down in the casing. Surging should be started slowly at first and the speed increased as the work progresses until it reaches the fastest limit at which the tools can be operated without excessive slap of the cable.

After the casing begins to fill up with sand, surging should be discontinued and the sand removed with the bailer. This operation is repeated until all the material that will come into the well has been removed. After surging is completed, the well should be pumped at its maximum rate for several days. The pumping opens up the water-bearing formations in a greater area than can be reached by the surging process.

Surging devices are of two general types, solid surge blocks and valve surge blocks. Solid surge blocks when operated up and down in the well create an alternating inward and outward movement of water through the perforated section of the casing. This action disturbs the finer sand particles, prevents bridging and closing of the openings between the larger particles and draws the finer particles into the well. The new mixture of particles around the perforations will have a higher porosity and permeability than the original formation.

Although solid surge blocks are the most common type used, under some conditions they will not be as effective as the valve type. This is usually the case for wells of low yield. Sometimes there will be a tendency for the solid surge block to force the water out of the well and back into the formation. If a tendency to lose water persists, it is a good indication that a valve type block should be used.

Although many types of valve blocks may be made, the essential feature is a block with port holes drilled through it with a valve of leather over the portholes. When the valve block is operated in a well, the water is pulled forcibly into the well on the up-stroke of the block. On the downstroke, the water is forced out of the well but, due to water escaping upward through the valves, the water is forced out at less velocity than when it is pulled into the well.

Practically all drillers will have the materials available to construct surge blocks or plungers of various sizes. A simple surge plunger can be made by wrapping sacking or similar material around the drill stem or bailer. Fairly good results can be obtained with this arrangement if a fairly tight fit is obtained between the plunger and the well casing. The surge block or plunger is operated on the drilling line and is given the up and down movement by the spudding mechanism on the rig.

Development by Use of Air

The use of air is an effective means of developing a well when it is properly done. Development with air is a combination of surging and pumping. Large volumes of compressed air are suddenly released at the bottom of the well, producing a strong surging action and pumping at the same time, as with an ordinary lift pump. Developing with air is best suited to wells of small diameter and the depth of water in the well should exceed two-thirds of the total depth of the well.

In using air for development, a drop pipe and an air line are necessary. The drop pipe is lowered to within about two feet of the bottom of the well and the air line placed so it is a foot or two up in the drop pipe. The well is pumped by air until the water is free from sand. A valve on the air line is then closed and the pressure in the tank built up to 100 or 150 pounds. The air line is lowered to a foot or so below the drop pipe and the valve opened quickly, allowing the air to rush into the well under full pressure. There will be a brief forceful surge of water and, if the air line is then pulled back into the drop pipe, a strong reverse flow will be produced up the drop pipe, effectively agitating the water-bearing formation. The cycle of surging and pumping is continued until the water is free from sand, indicating that the development work is complete.

Development by Pumping

The easiest and most commonly used method of developing a well
in sand or gravel is by pumping. There are several methods of
pumping used, the most common one being the process known as
"rawhiding" the well. A large-capacity pump should be used
and the suction line should be long enough to reach nearly to
the bottom of the well so that the pump will pick up sand
carried into the well by the developing process.

The well should be pumped slowly at first, with a gradual in-
crease in rate. At each rate, the pumping should be continued
until no more sand is discharged by the well. This procedure
should be continued until the maximum capacity of the pump or
the well is reached. The pump should not be shut down until
this preliminary pumping is completed. If pumping is stopped
during this stage, there is danger of sand clogging the well
or locking the pump. If pumping is started at maximum rates,
there will be a tendency for sand particles to bridge.

After pumping has continued at the maximum rate until the
water is free from sand, the pump should be shut down until
all the water in it has drained back into the well and the
water table has returned approximately to normal. When the
water level in the well has returned to approximately its
original level, the pump should be started and the process
repeated. This alternate starting and stopping of the pump
stirs up the material around the casing and causes the fine
material to move into the well where it is removed by pumping.

The time necessary to develop a well by this method varies
within wide limits. Occasionally, only a few hours are re-
quired but usually a well should be pumped from 48 to 72 hours
with the process of rawhiding repeated at intervals throughout
the time. The development and testing of a well should be
done with a test pump. The large amount of sand which goes
through the pump during development and testing does consider-
able damage and, if a new pump is used, it may lead to diffi-
culty within a short time after the pump is installed.

The above method has been effective in developing many wells
to their maximum capacity. Records are available on wells
which have more than doubled their yield during 72 hours of
development by pumping, without any increase in drawdown.
Continued pumping after this period has often resulted in
further appreciable increases in yield.

Backwashing

In developing wells by backwashing, the water is forced out
through the perforations by means of the pressure of air on
the water, but it cannot be used unless the water in the well
stands at a considerable height above the perforated part of
the casing. When this method is used, the top of the casing
is sealed with an airtight cap through which the air line
extends. The air line is equipped with a three way valve so
that the pressure in the well can be released at any time.
When air is turned into the air line, the pressure forces the
water in the well out through the perforations. When the air
begins to escape through the perforations, it is shut off and
the pressure in the well is released by opening the valve. A
pressure gage on the air line will show when the pressure has
built up enough to force air through the perforations. As
soon as the air starts to escape, the pressure on the gage
will no longer rise. When the pressure is released, the water
will flow back into the well, carrying fine sand with it.

The process should be repeated until no more sand is brought
in. The cap is then removed and the sand is removed with the
bailer. To make this method more effective, it should be
combined with pumping by air.

Developing with Dry Ice

Developing with dry ice (carbon dioxide) has met with consid-
erable success under some conditions but, in other instances,
it has been of no value and a few cases are known where the
well has been damaged by its use. The action is similar to
backwashing the well except that the pressure is built up by
the evaporation of the dry ice. When using dry ice, a relief
valve or opening should be provided to allow the gas to
escape.

Acidizing Wells

Muriatic acid is often effective in increasing the yields of
water from wells in limestone or wells in which the water-
bearing sands or gravel are partially cemented by lime.

In treating wells, dilute acid (usually a 15 percent solution) is commonly used. Usually the acid is introduced through a length of tubing extending into the well. If this is not possible, the acid may be introduced through the pump but this is likely to harm the pump and is not recommended except as a last resort. The quantity and method of employing acid depends upon a number of variable factors such as the size, depth and construction of the well, and geological conditions at the well.

Use of Chemical Dispersing Agents
for
Developing and Cleaning Wells

The use of chemicals for cleaning and developing wells has become increasingly widespread in recent years. Although few adequate tests have been made in the southwest, the results obtained would justify use of these materials in many areas.

A big advantage in the use of chemicals is that they can be used on wells where the pump has already been installed, no special equipment is needed, the materials can be safely handled, the work can be done by the farmer, and the cost is relatively inexpensive when compared with other methods.

Chemicals are effective in dispersing clay and silt and in removing lime, iron and other encrustants. Because of these properties, the products are of considerable value in the initial development of new wells, where these materials are present, and in cleaning old wells, where the screen or casing has become encrusted, thereby reducing the yield.

Procedures for treating new wells or cleaning old ones are similar for all such products and are outlined below. Before starting the cleaning process, check and record the drawdown and yield of the well. This information is essential in determining the amount of improvement obtained.

Recording the drawdown will give an indication of when maintenance cleanings should be carried out in the future. When the drawdown has increased, a short cleaning process should restore the well to normal.

In general, the following procedures are used when cleaning or developing wells with chemicals:

1. Pour the solution into the well in quantity recommended by the manufacturer.

2. Surge the well at least 12 times with a surge plunger, compressed air, or by starting and stopping the pump. If the pump is already installed and is used for surging, the water should be raised nearly to the surface but not pumped from the well. The pump is then stopped and the water allowed to drain back into the well. When the pump stops running backwards, start the motor again and repeat the operation. This action produces a vigorous agitation which helps remove the deposits that have been loosened by the solution and also forces the solution into the surrounding strata.

3. Repeat the surging operation every four hours for the period recommended by the manufacturer. At the end of this period, pump the well for at least one hour. During the pumping, stop the pump and surge the well three or four times, at about ten minute intervals. (Be sure the pump has stopped running backward before starting again.) The turbid water noted after the surging is indication of the removal of fine material and as long as the turbidity is present, pumping should be continued.

4. After the pump has operated sufficiently to steady pumping conditions, check the yield and drawdown. Recharge the well and repeat the operation as outlined above until no further improvement is noted. Three to five charges may be necessary before the operation is completed.

In some wells where a clay layer overlies a fine water-bearing stratum, blocks of clay may slump down around the perforated section of the casing if a considerable amount of the fine material is removed by pumping. Some of the perforations will be sealed, with a consequent reduction in yield of the well. The use of chemicals to disperse the clay so it can be drawn into the well and removed is about the only feasible method by which the well may be restored to its original capacity.

TESTING WELLS

After the well has been developed, it should be thoroughly tested. The characteristics of the well as determined by testing will govern the type and size of pump, needed, the economical yield and the horsepower required to lift that volume of water.

The information to be obtained from a well test is the static water level, the yield and the depth to water when the well is being pumped at different rates. From these data, the yield, drawdown and specific capacity can be computed. If the water-bearing formations are of great thickness or the water is under artesian pressure, it is not necessary to pump the well at its maximum rate to determine its characteristics, because the yield is almost directly proportional to the drawdown. That is, if a drawdown of 10 feet yields 100 gallons per minute, a drawdown of 20 feet will yield approximately 200 gallons per minute. This is usually not true for shallow wells and wells where the water is not under artesian pressure. For this reason, testing of these wells should be carried on until the maximum capacity of the well is reached.

Before starting the pumping test, the depth to the static water level should be measured. This can easily be done with a steel tape. Putting blue carpenter's chalk on the lower end of the tape will make it easy to read the water mark on the tape. The well is then pumped at the maximum rate until the drawdown and discharge become constant. When this condition is reached, the discharge of the pump and the depth to water are measured. The pumping rate should then be reduced until the drawdown is about one-fifth less than it was before. When the drawdown becomes constant, the discharge and drawdown are again measured. The discharge is then reduced until the drawdown is two-fifths less than the maximum. This process is repeated until the water level in the well returns to its original level.

From the data obtained, a curve is plotted showing the relation between the drawdown and the discharge. It is evident from an examination of the typical curve shown in Figure 5, page 29, that the higher the rate at which a shallow well is pumped, the smaller will be the discharge per foot of drawdown. For this reason, it is usually not economical to pump a well of this type at maximum capacity. The relation of the

discharge to the drawdown is influenced by the fact that the area through which the water can enter the well is reduced as the drawdown increases. As the curve shows, it is usually most economical to pump water wells at a rate which will lower the water surface about half the distance to the bottom of the well. From this point, the drawdown must be practically doubled to obtain about one-fourth more water.

The discharge from artesian wells is almost directly proportional to the drawdown, so long as the drawdown does not exceed the artesian pressure head. When the drawdown exceeds the artesian pressure head, the area through which water can enter the well is reduced and, consequently, the discharge will not increase in proportion to the drawdown. In artesian wells, about one-half of the maximum capacity of the well is obtained when the drawdown is equal to 1/2 the depth of the water column.

Estimating Yields and Drawdowns:

After a pumping test has been made and drawdown measured, it may be important to determine the quantity of water that could be obtained at different drawdowns.

To obtain this information, the curves in Figure 5 should be used. To show how this curve can be used, let us calculate the most economical water yield from a specific well. The water stands 75 feet in this well and the pumping test yielded 1,470 gallons per minute with a drawdown of 23 feet. This is 30 percent of the total possible drawdown, which is the static height of the water column. The curve shows that at 30 percent of the maximum drawdown, the well should produce 52 percent of the maximum yield. If 1,470 gallons per minute is 52 percent, the maximum yield of this well, or 100 percent, would be 2,827 gallons per minute. However, we can see from the curve that the most desirable rate is one which will lower the water level 50 percent (38 feet) and yield 77 percent of the maximum, or 2,253 gallons per minute.

Measuring Drawdown

There are two satisfactory methods of measuring drawdown in

wells. Many deep-well pumps are equipped with pressure gages
and air lines of known lengths. The air line is simple to
install and operates automatically but its use must be under-
stood to obtain correct results. Air lines should be made a
part of each pump installation so that frequest checks on
water level can be made.

The air line is usually a copper tube one-eighth to one-quarter
inch in diameter or one-fourth inch galvanized pipe with one
end connected to a pressure gage at the surface and an air
valve just below the gage. The lower end of the pipe is open.
The pipe must be air tight and must extend well below the low-
est pumping level. Air pressure can be furnished by a tank
connected to the line or by means of an ordinary tire pump.
The pressure gage indicates the number of pounds pressure nec-
essary to counterbalance the depth of water outside the air
line. Practically all gages are now calibrated in feet, so
that direct readings of the water level in the well can be
made.

Another satisfactory and accurate method of measuring water
level is by means of an electric sounder. There are numerous
types of sounders but the basic principles are the same. An
electric sounder can be made by taking a length of insulated
electrical zip cord, with one end shielded to form an elec-
trode or contact. The two wires are separated inside the
electrode. The wires are connected to flashlight batteries
and a sensitive ammeter at the surface. When the electrode is
lowered into the well, the electric circuit is completed when
the ends of the wires touch the water. Contact is registered
on the ammeter.

It will be found that even careful measurements of drawdown
will vary for the same rate of yield. The water level in a
pumping well is constantly moving. Usually it is going down,
slowly but steadily. Measurements for drawdown should usually
not be recorded until three readings, made an hour apart, show
no substantial difference. When this point is reached, it can
be assumed that equilibrium has been reached between the water
being pumped out of a well and water entering the well.

Measuring Yield

An accurate test of any well involves an accurate measurement
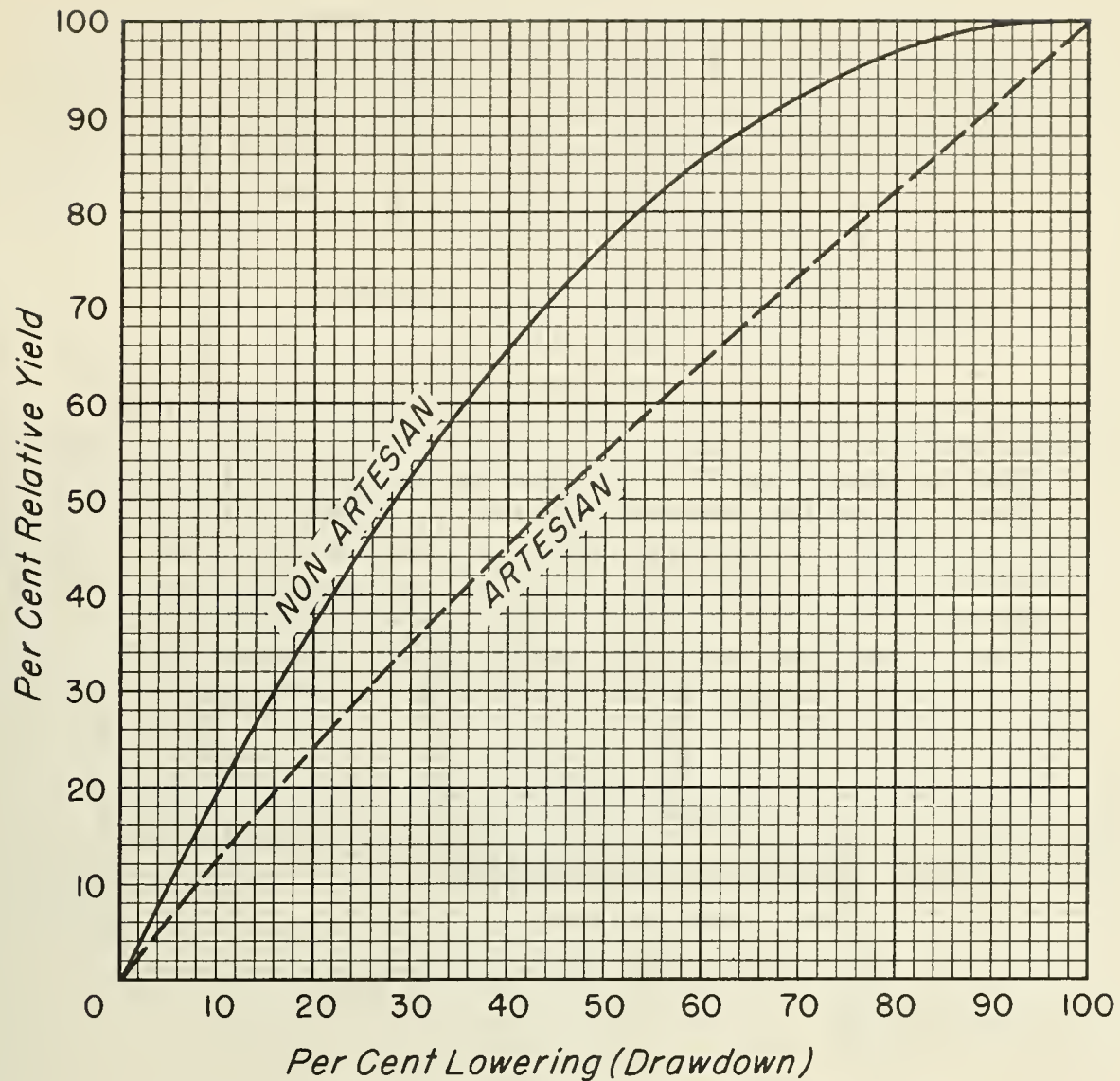
Figure 5. Relation of Drawdown to Yield

Example: The water stands 75 feet in a well and the pumping test yielded 1470 g.p.m with a drawdown of 23 feet. This is 30% of the total possible drawdown. The curve shows that at 30% of the maximum drawdown, the well will produce 52% of the maximum yield. 1470 g.p.m. is 52% so the maximum yield or 100% would be $\frac{1470}{.52}$ = 2827 g.p.m. The curve shows that 77% of the maximum capacity can be obtained with a 50% (38 feet) drawdown. 2827 x .77 = 2253 g.p.m. yield with a 38 foot drawdown.

From Bulletin 1238, Edward E. Johnson Inc. Revised 1947

of the yield. The common methods of measuring water are by
means of orifices or the use of weirs. As the use of these
methods requires a knowledge of proper methods and as numerous
publications dealing with the measurement of water are avail-
able, the topic will not be discussed here.

Coordinate Method of Estimating Flow from Pipes

In many cases, it is not practical to measure the discharge of
a pump by means of weirs or other devices but it may be impor-
tant to obtain a reasonable estimate of the yield. A close
approximation (between 90 and 100 percent accurate) of the a-
mount of flow can be made by means of a few measurements and
without any equipment other than a board with a straight edge,
and a rule. For horizontal pipes flowing full, the formula
$Q = A \times X$ will give sufficiently accurate results for many
practical purposes. For somewhat more accurate results, the
formulas $Q = 1.015 A \times X$, or $Q = 0.818 D^2 X$ may be used. The
chief difficulty in obtaining accurate results by this method
is the difficulty in accurately measuring the coordinates. The
flow from pipes may be measured whether the pipe is discharging
vertically upward, horizontally or at some angle with the hori-
zontal.

Q - gallons per min-
ute.

X - Horizontal dist.
in inches.

Y - 12 inches.

A - Area of pipe in
square inches.

D - Diameter of pipe
in inches.
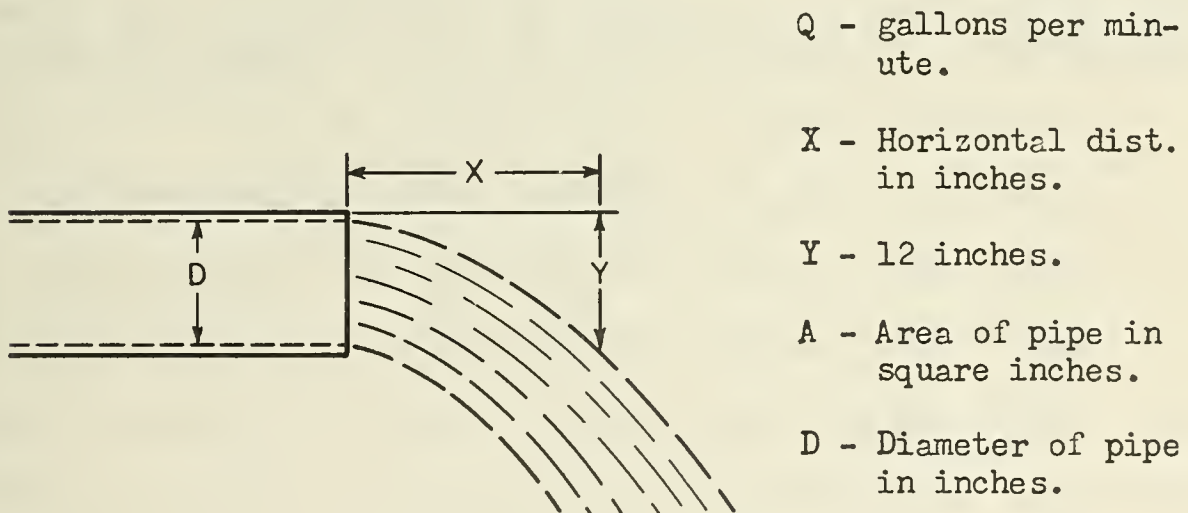
Figure 6 - Flow From Horizontal Pipes Flowing Full.

Where the fall of water is insufficient to obtain a Y of 12 inches, a Y of six inches may be used. In this case, the formula $Q = 1.157 D^2 X$ is used.

TABLE 2

Flow From Horizontal Pipes Flowing Full

(Gallons per Minute)

$$Q = 0.818 \ D^2 \ X$$

Pipe Dia. "D" in Inches	Area of Pipe in Sq. Inches	Measured Distance "X" in Inches (Y = 12 inches)										
		12	14	15	18	20	22	24	26	28	30	32
2	3.14	39	46	52	59	66	72	78	85	91	98	104
4	12.57	157	183	204	235	261	288	314	340	366	392	418
6	28.27	354	414	472	530	590	650	708	767	825	885	945
8	50.27	627	731	836	940	1048	1150	1252	1360	1460	1570	1670
10	78.54	980	1145	1308	1470	1635	1800	1960	2120	2285	2445	2620
12	113.1	1413	1650	1880	2120	2360	2580	2820	3061	3300	3520	3760

For slightly inclined pipes, measure X parallel to the pipe and Y vertically.
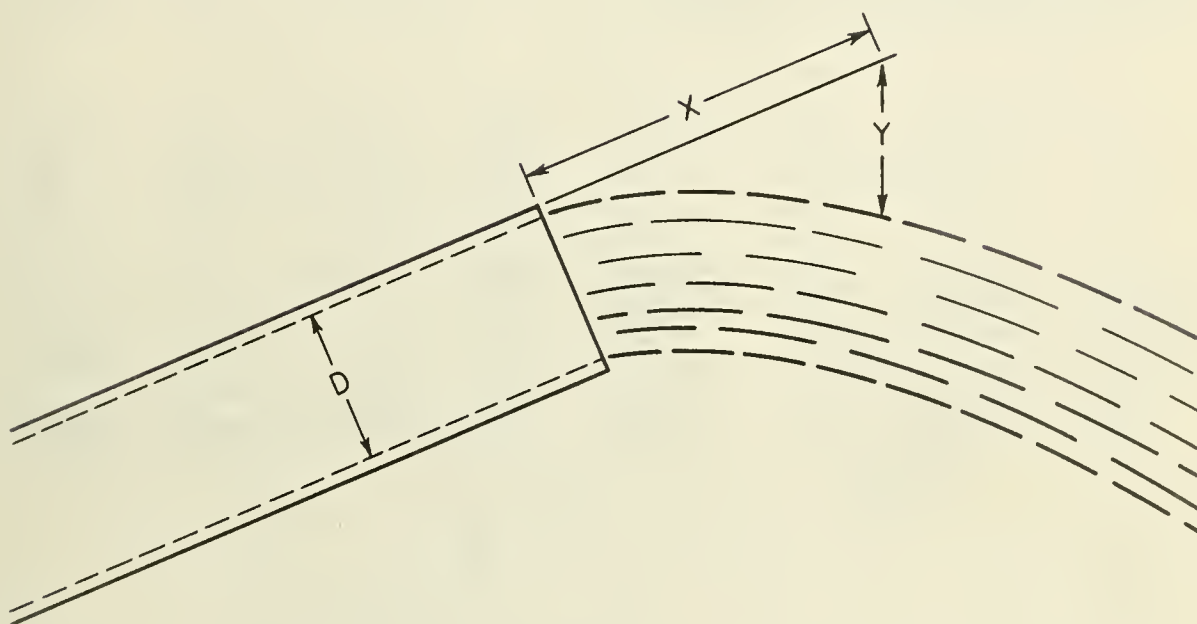
Figure 7 - Measuring Flow From Inclined Pipes.

For partially filled pipes, measure the freeboard (F) and the inside diameter (D) and calculate the ratio of F/D (in percent.) Measure the flow as for a full pipe and calculate the discharge. The actual discharge will be approximately the value for a full pipe of the same diameter multiplied by the correction factor from the following table:

F/D Percent	Factor	F/D Percent	Factor	F/D Percent	Factor	F/D Percent	Factor
5	0.981	30	0.747	55	0.436	80	0.142
10	0.948	35	0.688	60	0.375	85	0.095
15	0.905	40	0.627	65	0.312	90	0.052
20	0.858	45	0.564	70	0.253	95	0.019
25	0.805	50	0.500	75	0.195	100	0.000
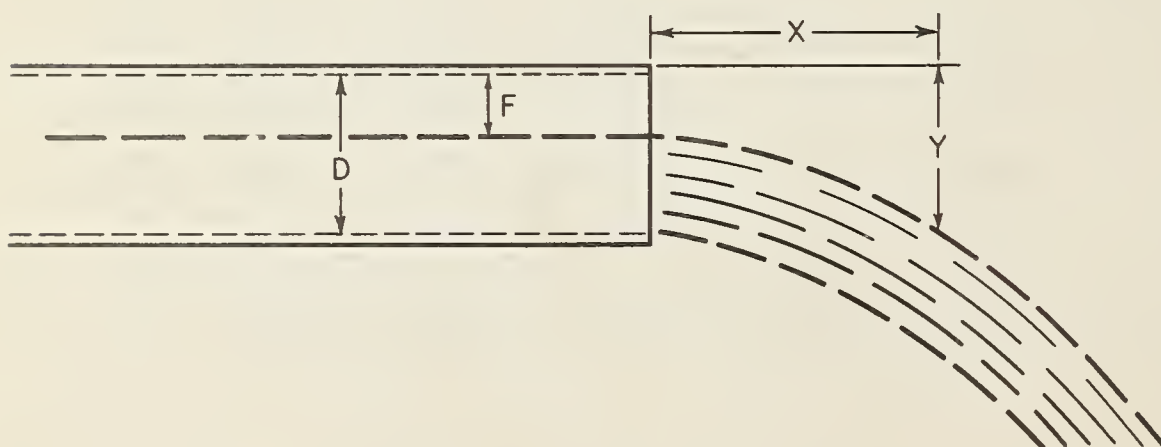
Figure 8 - Measuring Flow From Partially Full Horizontal Pipes.

For estimating the flow from vertical pipes measure the
maximum height H in inches to which the water jet rises
above the pipe.

$$Q \ (G. \ P. \ M.) = 5.68 \ CD^2 \ \sqrt{H}$$

Where D = Inside diameter of
pipe in inches.

H = Jet height in
inches.

C = A constant, varying
from .87 to .97 for
pipes 2 to 6 inches
in diameter and
heights 6 to 24
inches.
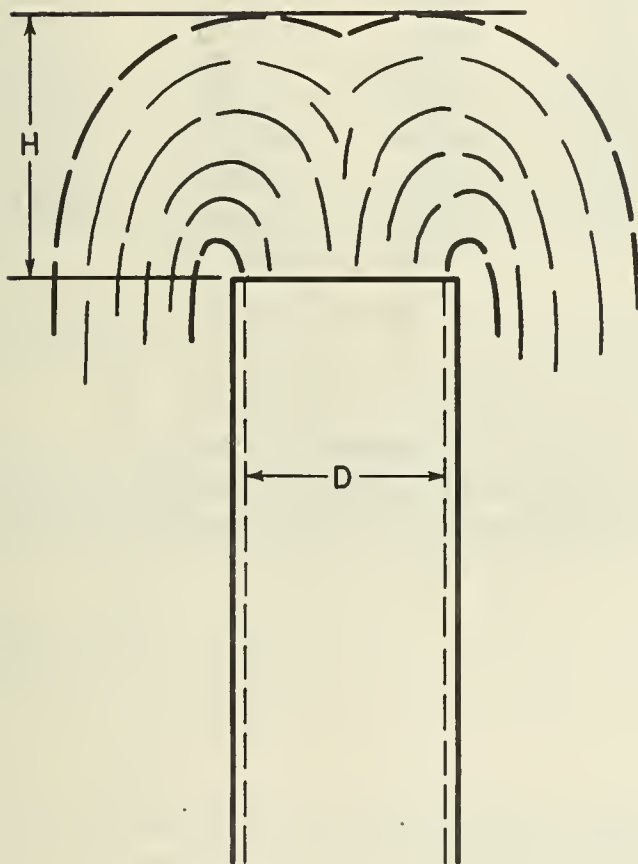
Figure 9 - Measuring Flow From Vertical Pipes.

TABLE 3

Flow From Vertical Pipes

FLOW FROM VERTICAL PIPES
(Approximate Gallons per Minute)

HEAD IN INCHES	INSIDE DIAMETER OF PIPE IN INCHES					
	2	3	4	6	8	10
3	35	77	135	311	569	950
3-1/2	38	85	149	341	626	1055
4	41	92	161	369	687	1115
4-1/2	44	98	172	396	733	1200
5	47	104	182	420	779	1280
5-1/2	49	109	192	444	825	1350
6	52	115	202	469	872	1415
7	57	126	219	509	949	1530
8	61	135	236	548	1025	1640
10	69	153	265	621	1155	1840
12	76	169	294	685	1275	2010

The Regional Engineering Handbook contains nomographs for estimating flow from pipes. A copy of these nomographs 6-L-12009-2-1-(2) and 6-L-12009-2-2-(2) should be obtained by all Soil Conservation Service personnel who frequently need to determine the flow of water from wells.

PUMPING COSTS

The question of whether a pumping operation will be economically feasible is becoming increasingly important. This is difficult to determine and must be judged for each individual farm. In general, the formula, interest on farm investment + taxes + water cost = crop, will determine the feasibility of a pumping operation.

Each water user can calculate the cost of his own pumping by following the methods given. Cost of pumping = Fixed charges + Operating costs.

Fixed charges include depreciation + interest + taxes (if levied) + insurance (if carried.) Operating costs are fuel or power + maintenance + lubricants + labor for operating the plant.

Depreciation: Divide the cost of each installation (well, pump, transmission, power plant and housing) by its prospective life. Add individual items to get the total annual depreciation.

Interest: This is seldom considered, but the total investment should earn the prevailing interest. For practical purposes, and to allow for declining value of the installation, the average annual interest cost over the life of the equipment should be one-half of the prevailing interest.

Fuel: If the user keeps an actual record of the fuel used during the year, this will be the most accurate cost to use. If no records have been kept, the following formula will give approximate results: Total hours of operation =

$$\frac{\text{Total acre-feet pumped X 12 X 448.}}{\text{Gallons per minute}}$$

Multiply the number of hours of operation by the fuel consumed per hour for the annual fuel consumption.

Maintenance: If the cost of maintenance is not known from actual records, a charge of from 20 cents per acre-foot for electric plants to 35 cents for natural gas and butane will fit average conditions.

Lubricants: The best figure is the actual recorded expenditure during the year. If records have not been kept, charges of five to fifteen cents per acre-foot will approximate average conditions.

Labor: Record or estimate time spent in operating the pumping plant to get the true-cost of pumping.

Total Cost: Addition of the above charges will give the total annual cost of pumping water. The cost per acre-foot can be determined by dividing by the recorded or estimated acre-feet

pumped during the year.

Many operators are interested in estimating the fuel cost per acre-foot for a proposed well. Chart 1 shows the fuel cost of lifting one acre-foot of water one foot. For internal combustion engines, the fuel costs given should be divided by (1.00 - 0.035 elevation in feet.)
$$\overline{1000}$$

Factors derived from this formula are shown below and the costs shown on Chart 1 should be divided by these factors to get the corrected cost:

ELEVATION ABOVE SEA LEVEL

2000 feet - .965
2500 feet - .913
3000 feet - .895
3500 feet - .873
4000 feet - .856
4500 feet - .843
5000 feet - .825
5500 feet - .808
6000 feet - .790

Example: To determine the fuel cost to lift one acre-foot of water to the surface. A pump using butane for .fuel at a cost of .11 per gallon, with 70 percent efficiency and a pumping head of 80 feet, elevation of pump 4500 feet. In Chart 1, the cost given for lifting one acre-foot one foot is 2.5 cents. The factor for 4500 feet is 0.843 $\frac{.025}{.843} = .029.$

.029 X 80 = $2.32 for lifting one acre-foot of water to the surface.

(Pumping head includes depth to static water level + draw-down + additional lift to storage reservoir.)

Chart 1. Pumping Power and Fuel Costs

(Adapted from standard chart 6-L-12003-41
Engineering Handbook, Soil Conservation Service,
Southwest Region.)

Remarks	Type of Fuel	Fuel Cost	FUEL COSTS IN CENTS FOR LIFTING ONE ACRE-FOOT AGAINST ONE FOOT PUMPING HEAD (1 - 2) Pump Efficiency			
			50%	60%	70%	80%
		Cents/ KWH	cents	cents	cents	cents
Efficiency of 88 percent is assumed for motor.	E L					
Motor is direct con-	E	0.8	1.86	1.55	1.33	1.16
nected so there is no	C	1.0	2.32	1.94	1.66	1.45
transmission loss.	T	1.2	2.78	2.32	1.99	1.74
	R	1.4	3.25	2.71	2.32	2.03
One acre-foot pumped	I	1.6	3.72	3.10	2.65	2.32
at 100% wire to water	C	1.8	4.18	3.48	2.98	2.61
efficiency is equiva-	I	2.0	4.64	3.87	3.32	2.90
lent to	T	2.5	5.80	4.83	4.13	3.63
1.02KWH or 1.37BHPH	Y	3.0	6.97	5.81	4.97	4.35
		Cents/ gal.				
Computed on basis of		8	2.78	2.31	1.98	1.74
0.12 gal. of gasoline	G	9	3.12	2.60	2.22	1.95
developing 1 BHPH at	A	10	3.47	2.89	2.47	2.17
engine, using 70	S	11	3.82	3.18	2.72	2.39
octane gasoline.	O	12	4.16	3.47	2.96	2.60
	L	13	4.51	3.76	3.21	2.82
A transmission	I	14	4.86	4.05	3.46	3.04
efficiency of 95%	N	15	5.21	4.34	3.71	3.26
is assumed	E	16	5.55	4.62	3.95	3.47

Chart 1. Continued

Remarks	Type of Fuel	Fuel Cost	FUEL COSTS IN CENTS FOR LIFTING ONE ACRE-FOOT AGAINST ONE FOOT PUMPING HEAD (1 - 2)			
			Pump Efficiency			
			50%	60%	70%	80%
		Cents/ gal.	cents	cents	cents	cents
Computed on basis of 0.075 gal. of Diesel oil 142.000 TU per gal. developing 1 BHPH at engine .	D I E S E L	3 4 5 6 7 8	0.65 0.87 1.09 1.30 1.52 1.74	0.54 0.72 0.91 1.09 1.27 1.45	0.47 0.62 0.78 0.93 1.09 1.24	0.41 0.54 0.68 0.82 0.95 1.09
A transmission efficiency of 95% has been assumed.	O I L	9 10 11	1.95 2.17 2.39	1.63 1.81 1.99	1.40 1.55 1.71	1.22 1.36 1.50
		Cents/ 1000 cu.ft.				
Computed on basis of 11 cu. ft. gas developing BHPH at engine with gas having a heat content of 1150 BTU per cu. ft.	N A T U R A L	15 20 25 30 35 40	0.48 0.64 0.80 0.95 1.11 1.27	0.40 0.53 0.66 0.80 0.93 1.06	0.34 0.45 0.57 0.68 0.79 0.91	0.30 0.39 0.49 0.59 0.69 0.79
A transmission efficiency of 95% has been assumed.	G A S	45 50 55	1.43 1.59 1.75	1.19 1.33 1.46	1.02 1.14 1.25	0.89 0.99 1.08

Chart 1. Continued

Remarks	Type of Fuel	Fuel Cost	FUEL COSTS IN CENTS FOR LIFTING ONE ACRE-FOOT AGAINST ONE FOOT PUMPING HEAD (1 - 2)			
			Pump Efficiency			
			50%	60%	70%	80%
		Cents/ gal.	cents	cents	cents	cents
Computed on basis of						
0.11 gal. of Butane		5	1.59	1.33	1.14	1.00
(100,000 BTU per gal.)	B	6	1.91	1.59	1.36	1.19
developing 1 BHPH at	U	7	2.23	1.86	1.59	1.39
engine.	T	8	2.54	2.12	1.82	1.59
	A	9	2.86	2.39	2.04	1.79
	N	10	3.18	2.65	2.27	1.99
A transmission	E	11	3.50	2.92	2.50	2.19
efficiency of 95%		12	3.82	3.18	2.72	2.39
has been assumed.		13	4.13	3.45	2.95	2.59

(1) For fuel costs where an internal combustion engine is above 1000 feet in elevation, divide fuel cost given by

$$(1.00 - 0.035 \frac{Elev. \ in \ feet}{1000}) \quad \text{Note: See factors Page } 37.$$

(2) The fuel costs given are for average operating conditions over a period of years with the engine kept in average repair. Most new engines will perform better than indicated above.

(3) KWH is abbreviation of kilowatt hour of energy.

(4) BHPH is abbreviation of brake-horsepower-hour of energy.

For fuels having heat content other than as given, fuel cost is approximately inversely proportional to heat content.

CONTRACTS AND SPECIFICATIONS

Few individuals take the trouble to draw up any form of contract when having a well drilled. Although an oral contract is binding on both parties, it is a source of misunderstanding because it depends upon the memory of the parties, and agreement is not always reached. Contracts and specifications which are too rigid lead to excessive costs for the job and should be avoided.

The Soil Conservation Service is not a legal authority and where a legal contract is required, an attorney should be consulted. However, experience has shown that a thorough understanding and agreement on at least the following points are necessary if a satisfactory job is to result:

SPECIFICATIONS:

1. The well shall be started at the surface with (12" standard pipe) with a weight per foot of _____ lbs., and carried to a depth of about (300) feet. If two or more lines of casing are run, an ample overlap will be allowed and an effectual seal will be set.

2. Drilling: The well shall be drilled in such vertical alignment that, after perforating and testing, a deep-well pump having a clearance of one (1) inch on each side may readily be installed and operated without undue stress or wear due to excessive inclination of the shaft.

3. Well Record: The contractor shall keep and furnish to the owner an accurate log of materials passed through, water-bearing strata, progress in sinking the casing, depth of perforations, static water level, drawdown, and record of testing and development work carried out.

4. Perforating: The casing will be perforated in all water-bearing strata (except quick sand) likely to yield a satisfactory supply of good quality water.

Perforations will be made with a Mills knife or equivalent perforator, making holes (1/4 X 4" to 1/2 X 4") as determined by the character of the formation.

5. Developing the Well: After completion, the well shall be surged thoroughly with a surge block, bailer or other equipment, until sand-free water is obtained. The work of surging shall be paid for at the rate of _____ per hour.

6. Testing: Immediately after the well has been surged and bailed, it shall be tested by a deep-well turbine pump furnished by the driller, which shall have a capacity in excess of the expected yield, and capable of pumping at variable rates. The pump shall be operated continuously for a total of _____ hours and an air line or other suitable method shall be used to measure the drawdown periodically during pumping.

7. Unit Prices: The unit price per foot of well will be _____ and will include the cost of moving to and from the well site and setting up the equipment. The cost of perforating will be included in the unit price unless otherwise stated. Test pumping will be paid for at the rate of _____ per hour and will include time of installing and removing the pump.

REFERENCES

1. Anderson, Keith E.
        1948. WATER WELL HANDBOOK. Missouri Water
        Well Drillers Association, Rolla, Mo.

2. Bennison, E. W.
        1947. GROUND WATER, ITS DEVELOPMENT, USES
        AND CONSERVATION. Edward E. Johnson, Inc.,
        St. Paul, Minn., 509 pp. Illus.

3. Code, W. E.
        1929. CONSTRUCTION OF IRRIGATION WELLS IN
        COLORADO. Colo. Experiment Station
        Bulletin 350. 22 pp.

4. Johnson, Edward E., Inc.
        1947. THE YIELD OF WATER WELLS.
        Bull. No. 1938 Revised. 6 pp. Illus.

5. Johnson, Edward E., Inc.
        TESTING WATER WELLS FOR DRAWDOWN AND YIELD.
        Bull. No. 1243. 8 pp. Illus.

6. Johnson, Edward E., Inc.
        1941. THE PRINCIPLES AND PRACTICAL METHODS
        OF DEVELOPING WATER WELLS.
        Bull. No. 1033, revised. 33 pp. Illus.

7. Rohwer, Carl.
        1940. PUTTING DOWN AND DEVELOPING WELLS FOR
        IRRIGATION. U.S.D.A. Circular No. 546, 87
        pp. Illus.

8. Rohwer, Carl.
        1940. SMALL IRRIGATION PUMPING PLANTS.
        U.S.D.A. Farmers Bull. No. 1857. 30 pp. Illus.

9. Rohwer, Carl.
        1950. THE HYDRAULICS OF WATER WELLS.
        U.S.D.A. S.C.S. Ft. Collins, Colo., 15 pp.
        Illus.

10.   Schwalen, Harold C.
            1925.   THE STOVEPIPE OR CALIFORNIA METHOD
            OF WELL DRILLING AS PRACTICED IN ARIZONA.
            Ariz. Agri. Expt. Sta. Bull. 112, 154 pp.   Illus.

11.   Tolman, C. F.
            1937.   GROUND WATER.
            593 pp. Illus.   New York and London.

12.   Turneaure, F. E., and Russel, H. L.
            1940.   PUBLIC WATER SUPPLIES.
            Fourth Edition Revised.

13.   Wood, Ivan B.
            1950.   PUMPING FOR IRRIGATION.
            U.S.D.A. Technical Paper 89, 40 pp.   Illus.